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ABSTRACT

The current standards-based and systemic reform has an overarching goal: high academic standards for all students. In achieving the goal of "science for all," the key is the construct of science achievement Ð what K-12 students should know and be able to do in science. This paper reviews and analyzes the conceptions of science achievement in major reform documents, including those on science content standards (NSES and Project 2061), performance standards (New Standards), and large Ðscale assessment frameworks (1996 NAEP and TIMSS). The analysis of these documents indicates that there is an overall agreement on the conceptions of science achievement. The documents consistently emphasize high achievement in terms of knowledge and abilities in science and technology in personal, social, and historical perspectives. Despite the overall agreement, there are also noticeable variations among the documents because of different contexts and purposes. Based on the synthesis of the conceptions of science achievement, the paper presents an aggregated view of science achievement. Science achievement is conceived of in terms of science content and science process. The components of science content include: (a) concepts and theories in physical, life, and earth and space science; (b) science, mathematics, and technology; (c) science in personal and social perspectives; (d) history and nature of science; and (e) unifying themes. The components of science process include: (a) scientific understanding; (b) scientific investigation; (c) scientific communication; and (d) scientific habits of mind. The components of science process cut across and intersect with the components of science content. The paper considers the implications of the aggregated view of science achievement for assessment and equity in large education systems. In large-scale assessments, some components of science achievement present challenges because it is difficult to operationalize them in concrete terms, to develop standardized procedures, to administer on-demand assessment, or to use

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multiple forms of assessment (e.g., observations, interviews, and products) in addition to written forms. Although equity is emphasized, there are tensions and dilemmas in considering equity related to science content standards and standards-based assessment. What counts as science and what should be taught in school science as presented in the content standards are often incompatible with ways of knowing and thinking in diverse cultures. The relative equity of standardized forms and alternative forms of assessment is under consideration. Major reform documents in science education consistently emphasize high achievement for all students. The available knowledge about assessment and equity, however, is limited. The difficulties with large-scale assessments are conceptual and practical, in terms of how to do the assessment within the confines of assessment settings. The difficulties with educational equity are ideological and cultural, in terms whose science should count and be taught in school science, in addition to practical matters of resources and opportunities. Now that science content standards are established, efforts should be focused on how to implement standards-based assessments and how to ensure access and achievement for all students. The alignment of assessment with the content standards, as well as the attainment of the standards by all students, are key challenges to standards-based and systemic reform in large education systems. (Author)

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Research Monograph No. 12

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Okhee Lee

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Abstract

The current standards-based and systemic reform has an overarching goal: high academic standards for all students. In achieving the goal of "science for all," the key is the construct of science achievement -- what K-12 students should know and be able to do in science. This paper reviews and analyzes the conceptions of science achievement in major reform documents, including those on science content standards (NSES and Project 2061), performance standards (New Standards), and large-scale assessment frameworks (1996 NAEP and TIMSS). The analysis of these documents indicates that there is an overall agreement on the conceptions of science achievement. The documents consistently emphasize high achievement in terms of knowledge and abilities in science and technology in personal, social, and historical perspectives. Despite the overall agreement, there are also noticeable variations among the documents because of different contexts and purposes.

Based on the synthesis of the conceptions of science achievement, the paper presents an aggregated view of science achievement. Science achievement is conceived of in terms of science content and science process. The components of science content include: (a) concepts and theories in physical, life, and earth and space science; (b) science, mathematics, and technology; (c) science in personal and social perspectives; (d) history and nature of science; and (e) unifying themes. The components of science process include: (a) scientific understanding; (b) scientific investigation; (c) scientific communication; and (d) scientific habits of mind. The components of science process cut across and intersect with the components of science content.

The paper considers the implications of the aggregated view of science achievement for assessment and equity in large education systems. In large-scale assessments, some components of science achievement present challenges because it is difficult to operationalize them in concrete terms, to develop standardized procedures, to administer on-demand assessment, or to use multiple forms of assessment (e.g., observations, interviews, and products) in addition to written forms. Although equity is emphasized, there are tensions and dilemmas in considering equity related to science content standards and standards-based assessment. What counts as science and what should be taught in school science as presented in the content standards are often incompatible with ways of knowing and thinking in diverse cultures. The relative equity of standardized forms and alternative forms of assessment is under consideration.

Major reform documents in science education consistently emphasize high achievement for all students. The available knowledge about assessment and equity, however, is limited. The difficulties with large-scale assessments are conceptual and practical, in terms of how to do the assessment within the confines of assessment settings. The difficulties with educational equity are ideological and cultural, in terms whose science should count and be taught in school science, in addition to practical matters of resources and opportunities. Now that science content standards are established, efforts should be focused on how to implement standards-based assessments and how to ensure access and achievement for all students. The alignment of assessment with the content standards, as well as the attainment of the standards by all students, are key challenges to standards-based and systemic reform in large education systems.

Current Conceptions of Science Achievement and Implications for Assessment and Equity in Large Education Systems

The vision of standards-based and systemic reform currently has an overarching goal: high academic standards for all students (McLaughlin, Shepard, & O'Day, 1995; Smith & O'Day, 1991). In science education, the goal of "science for all" is emphasized in reform documents, including *National Science Education Standards* [NSES] (National Research Council [NRC], 1996), *Science for All Americans* (American Association for the Advancement of Science [AAAS], 1989), *Benchmarks for Science Literacy* (AAAS, 1993), and *Scope, Sequence, and Coordination of Secondary School Science* (National Science Teachers Association [NSTA], 1992, 1995, 1996). These documents focus on defining and specifying science content standards.

Recent developments in science content standards are reflected in the assessment frameworks of large-scale projects (Raizen, 1997b), including the 1996 National Assessment of Educational Progress [NAEP] (National Assessment Governing Board [NAGB], 1994, 1996), the Third International Mathematics and Science Study [TIMSS] (Martin & Kelly, 1996; McKnight, Schmidt, & Raizen, 1993; Robitallie et al., 1993), and the New Standards Project (National Center on Education and the Economy [NCEE], 1997a, 1997b, 1997c). The key feature of these projects is to align the assessment with the new content standards in science.

Central to current reform in science content standards and assessment is the construct of science achievement -- what K-12 students should know and be able to do in science. The three professional organizations in science education (i.e., AAAS, NRC, and NSTA) and the three large-scale science assessment projects (i.e., New Standards, 1996 NAEP, and TIMSS) present varying degrees of commonalities and differences in their views of science achievement for all students. Because of these variations, there is a need to develop an aggregated view of science achievement based on the synthesis of these major reform documents. There is also a need to consider the implications for assessment and equity. This information will benefit policy makers, subject matter specialists, assessment experts, and evaluators of standards-based and systemic reform in general, as well as those involved in science education in particular.

This paper presents current conceptions of science achievement and implications for assessment and equity in the context of standards-based and systemic reform. The paper has four main purposes:

1. To review and analyze conceptions of science achievement in major reform documents and to identify commonalities and differences among these documents;

2. To describe an aggregated view of science achievement based on the synthesis of the conceptions of science achievement in these documents;

3. To consider the implications of the aggregated view of science achievement for large-scale assessments; and

4. To consider the implications of the aggregated view of science achievement for equity.

The Context for Science Achievement

Before addressing the main issues of the paper, it is important to consider these issues in the context of standards-based and systemic reform in science education. The following are discussed here: (a) the general context for science education reform; (b) the construct of science achievement; (c) the relationships among content standards, performance standards, and assessment frameworks, and (d) the rationale for including NSES, Project 2061, New Standards, 1996 NAEP, and TIMSS in this paper.

The General Context for Science Education Reform

Current science education reform is motivated by social and economic challenges, as well as academic purposes (Raizen, 1997a). Knowledge of science and technology has become essential for average citizens as they make decisions about personal and social matters, such as health, population growth, natural resources, environment, and safety. In addition, the expanding global economy demands a work force that is adequately educated in science and technology. In response to these social and economic challenges, science education reform documents define what all students should know and be able to do in science in order to participate effectively in society. These documents define science content standards in a comprehensive manner that includes not only science knowledge and inquiry, but also how science is related to personal, social, and historical perspectives.

The need for equity in the goal of "science for all" is obvious with the increasingly diverse student population in the U.S. Traditionally, some groups have not performed well in science and have been underrepresented in science-related careers, including students from diverse cultures and languages, students with disabilities, students from low socio-economic backgrounds, and female students. As the global economy expands, these student groups will enter the work force of the future. Thus, the emphasis on the achievement of high academic standards for all students, especially those who have traditionally been bypassed in science, is an important contribution of the reform documents. However, the concept of equity is not clearly articulated, and the plan to achieve equity is not well established (Atwater, 1994; Lee & Fradd, 1998).

Assessment plays a central role in determining the extent to which science education reform has achieved both high academic standards and educational equity (McLaughlin, Shepard, & O'Day, 1995; Smith & O'Day, 1991. Particularly, large-scale assessments at the state and national levels (e.g., NAEP and TIMSS) are used for accountability purposes as the general public and policy makers use these assessments to determine the effectiveness of reform efforts in meeting the standards and to monitor the progress in closing achievement gaps among diverse student groups. To be effective indicators of the reform, assessments must be aligned with content standards and be fair with all students.

Content standards, equity, and assessment are major areas of emphasis in standards-based and systemic reform. Standards-based reform aims to foster high achievement of all students by improving the education system at all levels (McLaughlin, Shepard & O'Day, 1995; Smith &

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O'Day, 1991). Systemic reform is an initiative to change the education system by addressing major components of the system together rather than individually (Cohen, 1996; Elmore, 1996). The ultimate goal of systemic reform is high achievement for all students, along with valid and fair assessment of student achievement. Because of such a close connection between the concepts of standards-based reform and systemic reform toward the common goal of high achievement for all students, this paper uses the expression "standards-based and systemic reform" in the context of large education systems.

The Construct of Science Achievement

The construct of "science achievement ," although deceptively simple and elusive, represents a great challenge:

> Measuring educational achievement is difficult from both a conceptual and a practical perspective. What counts as "achievement" is not always easy to discern. Even when a concept of achievement has been clearly explicated, ways and means for assessing it are not easily devised. (Robitallie et al., 1993, p. 36)
> The construct of science achievement can be interpreted according to the conceptual framework of intended, implemented, and attained curriculum in TIMSS (Robitallie et al., 1993, pp. 25-30).

First, the intended curriculum is the science content as defined at the national or the educational system level. The intended curriculum may be described in terms of science concepts, processes, and attitudes that students are expected to acquire. Second, the implemented curriculum is the science content as it is interpreted by teachers in their interactions with students. The implemented curriculum is influenced by the intended curriculum and can be described in terms of science concepts, processes, and attitudes. Finally, the attained curriculum consists of the outcomes of learning -- science concepts, processes, and attitudes that students have acquired.

According to this conceptual framework, the intended curriculum indicates science content standards at the educational system level; the implemented curriculum refers to science instruction at the classroom level; and the attained curriculum represents science achievement at the student level. At all three levels, what counts as science achievement (e.g., science concepts, processes, and attitudes in TIMSS) must be explicated. Then, ways to assess science achievement need to be established.

Content Standards, Performance Standards, and Assessment Frameworks

Content standards are broad and general statements of expected learning outcomes -- "Broad descriptions of the knowledge, skills, and understandings that schools should teach and students should acquire in a particular subject area" (McLaughlin, Shepard, & O'Day, 1995, p. 69). Content standards (e.g., NSES) can be further developed as benchmarks in terms of more specific learning outcomes at various grades or grade clusters (e.g., *Benchmarks for Science Literacy*).

Performance standards extend the content standards and benchmarks by specifying "how good is good enough" in learning outcomes (e.g., New Standards Project). Performance standards include "concrete examples and explicit definitions of what students should know and able to do to demonstrate proficiency in the skills, knowledge, and understanding framed by the content standards" (McLaughlin, Shepard, & O'Day, 1995, p. 70).

Assessments provide "an operational definition of standards, in that they define in measurable terms what . . . students should learn" (NRC, 1996, p. 6). Based on content standards, assessment frameworks identify expectations of learning outcomes to be assessed (e.g., NAEP and TIMSS). Assessment frameworks are used as blueprints for assessment activities. In this sense, assessment frameworks represents an interim step in translating content standards into assessment activities. The complexities and difficulties in aligning assessment with content standards are described later in the section on assessment.

Selection of Major Reform Documents in Science Education

This paper examines current conceptions of science achievement based on major reform documents in science education. These documents are: (a) two sets of documents on content standards, including NSES (NRC, 1996) and Project 2061 (AAAS, 1989, 1993); (b) a set of documents on performance standards in the New Standards Project (NCEE, 1997a, 1997b, 1997c); and (c) two sets of documents on assessment frameworks, including 1996 NAEP (NAGB, 1994, 1996) and TIMSS (Martin & Kelly, 1996; McKnight, Schmidt, & Raizen, 1993; Robitallie et al., 1993).

These reform documents are selected based on the following criteria. First, they provide guidelines for standards-based and systemic reform in large education systems. Second, they present comprehensive views of science and science education. Third, they cover science content for all grade levels, K-12. Finally, they are key documents that are representative of content standards, performance standards, and assessment frameworks in science education.

Based on the above criteria, the paper does not include some noteworthy efforts. For example, National Science Teachers Association documents (1992, 1995, 1996) are limited to the four science disciplines (biology, chemistry, earth and space science, and physics) traditionally studied at the secondary school level, grades 6-12. The Advanced Placement tests are administered to a small population of advanced high school students. The National Educational Longitudinal Study (NELS) focused only on 8th grade students before the current systemic reform in science had taken hold.

Conceptions of Science Achievement in Major Reform Documents: Commonalities and Differences

The five sets of documents all present views of science achievement in the context of current standards-based and system reform. In this section, commonalities and differences in the views of science achievement among these documents are analyzed. This analysis will provide the basis for developing a synthesis of current conceptions of science achievement, to be described in the next section.

For each set of documents, brief descriptions about its background, purposes, and the conception of science achievement are presented. The summary of the conceptions of science achievement in these documents is shown in Table 1. This table is organized using the categories given in the NSES standards because this document represents an effort to establish a general consensus of the science and science education communities in the nation. The table provides an overview of commonalities and differences among the five sets of documents at the categorical or topical level (see Raizen, 1997b, for general descriptions about these documents).

Several points need to be made clear about Table 1 and the discussion here. First, the sequence of the eight categories in NSES is slightly changed to fit with the other four sets of documents in Table 1. Second, in addition to the categories of "content standards" in NSES, the table includes "process standards" that cut across content standards. This distinction is based on "content" and "process" standards in mathematics standards (National Council of Teachers of Mathematics, 1989; also see AAAS, 1993, p. 209; Romberg, 1997), even though the authors did not state the distinction. New Standards, NAEP, and TIMSS identify science process standards. Although NSES and Project 2061 do not identify them as such, the documents emphasize process standards throughout the texts. Finally, the categories and terms in Table 1 are actual descriptors and expressions used in these documents. The documents sometimes use the same terms with different meanings, and different terms with similar meanings (as is explained in the next section).

Table 1

Conceptions of Science Achievement: Categories of Content and Process Standards from Major Reform Documents

	NSES (1996)	Project 2061 (1989, 1993)	New Standards (1997)	NAEP (1994, 1996)	
Content Standards	Physical science	The physical setting	Physical sciences concepts	Physical science	Ph
	Earth/space science	The physical setting	Earth and space sciences concepts	Earth science	Ea
	Life science	The living environment The human organism	Life sciences concepts	Life science	Lif
		The nature of mathematics The mathematical world			Sc
	Science and technology	The nature of technology The designed world	The designed world Impact of technology	The nature of science and technology	Sc
	Science in personal and social perspectives	Human society	Health, environment, safety, resources		En
	Science as inquiry	The nature of science Habits of mind	Scientific investigation	Scientific investigation The nature of science	Inv Na
	History and nature of science	Historical perspectives The nature of science	Science as a human endeavor Impact of science	The nature of science	Hi Na
	Unifying concepts and processes	Common themes	Big ideas and unifying concepts	Themes	

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Table 1 (Continued)

Category	NRC (1996)*	Project 2061 (1989, 1993)*	New Standards (1997)	NAEP (1994, 1996)	
Process Standards			Conceptual understanding	Conceptual understanding	U
			Scientific investigation Scientific tools and technologies	Scientific investigation	In U
			Scientific thinking	Practical reasoning	Tl
			Scientific communication		C

* Although the NSES and Project 2061 documents do not identify process standards, they emphasize these standards throughout the texts.

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National Science Education Standards

NSES (NRC, 1996) presents "a vision of science education that will make scientific literacy for all a reality" (p. ix) and provides a roadmap for how to achieve the goal. The development of the NSES document was guided by the following principles: (a) science is for all students; (b) learning science is an active process; (c) school science reflects the intellectual and cultural traditions that characterize the practice of contemporary science, and (d) improving science education is part of systemic education reform (pp. 19-21). The core of NSES involves science content standards, while "the separate standards for assessment, teaching, program, and system describe the conditions necessary to achieve the goal of scientific literacy for all students described in the content standards" (p. 13).

The content standards define "what students should know, understand, and be able to do in natural science" over the course of K-12 science education (p. 103). These standards indicate expectations for students' learning outcomes. While emphasizing "scientific inquiry is at the heart of science and science learning" (p. 15), the document presents eight categories of science content standards for grade ranges K-4, 5-8, and 9-12:

- Unifying concepts and processes
- Science as inquiry
- Physical science
- Life science
- Earth and space science
- Science and technology
- Science in personal and social perspectives
- History and nature of science

Project 2061

Science for All Americans (AAAS, 1989) is a major milestone in shaping the discourse of science education reform since late 1980s. This document provides a definition of scientific literacy for all students by the 12th grade in order to become educated citizens in society. Subsequently, *Benchmarks for Science Literacy* (AAAS, 1993) specifies the components of science content in greater detail at different grade levels, including 855 benchmarks at grade ranges K-2, 3-5, 6-8, and 9-12. Because of its specificity of learning outcomes, the *Benchmarks* document has often been used as guidelines for K-12 science curriculum.

Project 2061 defines science broadly to include natural science, mathematics, technology, and social science. The science content is organized thematically under four major dimensions (see the list below) (AAAS, 1989, p. ix). Then, the categories of the science content are outlined in terms of what students should know and be able to do as members of a scientifically literate society. Project 2061 highlights "both scientific knowledge of the world and scientific habits of mind" as fundamental in science and science learning (AAAS, 1989, p. 190).

The nature of science, mathematics, and technology

- The nature of science

- The nature of mathematics
- The nature of technology

Knowledge and skills in science

- The physical setting (physical and earth science)
- The living environment (life science)
- The human organism (life science)

Knowledge and skills in related disciplines

- Human society
- The designed world
- The mathematical world

Perspectives on science

- Historical perspectives
- Common themes
- Habits of mind

New Standards

The New Standards Project is designed to build an assessment system for school districts and states "to measure students' progress toward meeting national standards at levels that are internationally benchmarked" (NCEE, 1997a, 1997b, 1997c, p. 2). New Standards focuses on specifying performance standards and developing performance measures that teachers can use in English language arts, mathematics, science, and applied learning.

The New Standards assessment system has three interrelated components: performance standards, on-demand examinations, and a system of portfolio assessment. In science, by 1997, only performance standards have been developed. While content standards specify "what students should know and be able to do," performance standards go to the next level by specifying "how good is good enough" in attaining the content standards (p. 3). Performance standards translate content standards in a form so that assessment activities can be prepared.

The performance standards are derived directly from the science content standards in NRC (1996) and Project 2061 (AAAS, 1993) and, to some extent, international documents including TIMSS. The eight categories of performance standards in science are in two dimensions: (a) conceptual understanding that generally reflect the content standards in NSES and Project 2061 standards, and (b) "areas that need particular attention and a new or renewed emphasis," (NCEE, 1997a, p. 130), which represent important aspects of scientific inquiry as defined in NSES and Project 2061. New Standards include eight categories of performance standards in these two dimensions at the levels of elementary school (by the end of 4th grade), middle school (by the end of 8th grade), and high school (by the end of 10th grade):

Conceptual understanding

- Physical sciences concepts
- Life sciences concepts
- Earth and space sciences concepts
- Scientific connections and applications

- Big ideas and unifying concepts
- The designed world
- Health, environment, safety, resources
- Science as a human endeavor
- Historical and contemporary impact of science

Areas for particular attention

- Scientific thinking -- Scientific inquiry and problem solving by using thoughtful questioning and reasoning strategies, common sense and conceptual understanding, and appropriate methods of investigation
- Scientific tools and technologies -- Use of tools and technologies to collect and analyze data
- Scientific communication -- Effective scientific communication by clearly describing aspects of the natural world
- Scientific investigation -- Projects drawn from the following kinds of investigation, including experiments, fieldwork, design, and secondary research

National Assessment of Educational Progress

NAEP has been the only national-level assessment in various subject areas since its inception in 1969. The NAEP reports provide descriptive information about student achievement in subject areas, including science, for a national sample at grades 4, 8, and 12. The reports also provide group comparisons in terms of ethnicity, gender, and other demographic variables. The reports describe the relationships between achievement and certain background variables, such as time spent on homework and parent's educational levels. In addition to the national sample data, NAEP reports have provided voluntary state-by-state results since 1990.

Because of its prominence in assessment at the national and state levels, NAEP has tried to reflect changes in curriculum and emerging notions of teaching and learning, while maintaining the continuity of information that has been gathered in a long-term trend design (Glaser & Linn, 1997). The balance between change and continuity presents complicated questions (Jones, 1996). Along with the recent development of content standards, "the 1996 NAEP Science Achievement attempts to reflect a comprehensive, contemporary view of science so that those affected by the National Assessment are satisfied that it addresses the complex issues in science education without oversimplification" (NAGB, 1996, pp. 2-3). The 1996 NAEP science assessment is regarded as the best available means for determining the extent to which students across the nation and in each state achieved science content standards (Glaser & Linn, 1997; O'Sullivan, Reese, & Mazzeo, 1997).

In developing the assessment framework, 1996 NAEP considered Project 2061, NSTA, and TIMSS among its major sources. The framework has four main dimensions, each with sub-dimensions, as summarized below:

Fields of Science

- Earth science
- Physical science
- Life science

Knowing and Doing

- Conceptual understanding -- the ability to understand basic concepts and tools used in the process of a scientific investigation
- Scientific investigation -- the ability to use the appropriate tools and thinking processes in the doing of science
- Practical reasoning -- the ability to apply scientific knowledge to solve everyday problems

The Nature of Science

- The historical development of science and technology
- The habits of mind that characterize science and technology
- The methods of inquiry and problem solving

Themes

Third International Mathematics and Science Study

This is the largest study of mathematics and science performance ever undertaken, involving half a million students from 41 countries. The study provides information about student performance in mathematics and science for each country, as well as comparisons of performance among the countries. The study also provides information about contextual variables associated with student performance. These variables include curriculum analyses based on national or regional curriculum guidelines and commonly used textbooks, instructional practices, perceptions of teachers and principals, and instructional environments.

TIMSS developed curriculum frameworks in mathematics and science which were used for developing achievement tests for ages 9, 13, and the final year of secondary education (Martin & Kelly, 1996; Robitallie et al., 1993). Because TIMSS is an international study, the frameworks were designed to reflect the curricula of the participating countries. The frameworks have three main aspects: (a) subject matter content; (b) performance expectations (i.e., the kinds of performances that students are expected to demonstrate while engaged with the content); and (c) perspectives (i.e., attitudinal and motivational factors). The components of the content and the performance expectations aspects in science achievement tests include the following:

Content aspect

- Earth sciences
- Life sciences
- Physical sciences
- Science, technology, and mathematics

- History of science and technology
- Environmental issues
- Nature of science

Performance expectations aspect

- Understanding
- Theorizing, analyzing, and solving problems
- Using tools, routine procedures, and science processes
- Investigating the natural world
- Communicating

Analysis of the Documents: Commonalities and Differences

There is a general agreement on major categories of science content standards among the five sets of documents, as summarized in Table 1. There are also differences in some of the categories. Beyond this categorical analysis, there are both commonalities and differences in underlying views of science achievement among these documents, to be discussed next.

Commonalities. According to the analysis conducted by the Project 2061, there is about 90% agreement in content standards between the NSES and Project 2061 documents (AAAS, 1996, 1997). NSES also states that, "use of *Benchmarks* ... complies fully with the spirit of the content standards [in the NSES]" (NRC, 1996, p. 15). The performance standards in New Standards are "built directly upon the consensus content standards," (NCEE, 1997a, p. 3), particularly NSES and *Benchmarks for Science Literacy* (p. 130). The assessment frameworks by 1996 NAEP and TIMSS also reflect the recent developments of science content standards.

Together, these documents define science achievement in a comprehensive manner. Science achievement, i.e., what K-12 students should know and be able to do, includes concepts and theories in physical, life, and earth and space sciences; scientific inquiry or investigation; science with mathematics and technology; science in personal and social perspectives; the nature and history of science; unifying concepts or common themes; and scientific habits of mind. In addition, these documents define science achievement at different developmental levels (i.e. generally at elementary, middle, and high school years) and at certain depths of knowledge and abilities for all students.

Differences. The documents present noticeable differences in conceptions of science achievement. Main differences are described in three ways: (a) differences between the two sets of content standards; (b) differences between the two sets of content standards and the three assessment frameworks; and (c) differences among the three assessment frameworks.

Despite an overall agreement, there are noticeable differences between the NSES and Project 2061 documents (see AAAS, 1996, 1997 for more detailed discussion). First, Project 2061 defines science broadly to include natural science, mathematics, technology, and social sciences, whereas NSES focuses on natural science. The omission of mathematics in NSES has

been under debate, especially considering that NSES emphasizes scientific inquiry and that mathematics is integral in scientific inquiry.

Second, NSES views scientific inquiry as central in science and science learning, whereas Project 2061 emphasizes scientific knowledge and habits of mind. Scientific inquiry plays a special role in NSES. Scientific inquiry is both an overarching goal basic to science education and one of the eight categories of content standards. As an overarching goal, through scientific inquiry, students develop the knowledge and abilities for the other categories of content standards (NRC, 1996, p. 105). As a category of content standards, scientific inquiry includes both "the ability to conduct inquiry" (process) and "understanding about scientific inquiry" (content) (p. 105). In contrast, Project 2061 emphasizes scientific knowledge and understanding of core concepts and theories. Project 2061 also stresses scientific habits of mind, which are defined as certain values, attitudes, and skills shared in the science community.

Third, there is no clear comparison between NSES standards on "science as inquiry" and "history and nature of science" and Project 2061 standards on "the nature of science," "historical perspectives," and "habits of mind" (see Table 1). There is a significant overlap among these standards, and they are sometimes used interchangeably. As students engage in scientific inquiry, they come to understand the nature of science and the historical development of science (content) and also develop scientific habits of mind (process) (AAAS, 1993, p. 209; NRC, 1996, pp. 45-46, 50-51).

Several main differences are noted between the two sets of content standards and the three assessment frameworks. First, NSES and Project 2061 include science content primarily, although NSES stresses scientific inquiry and Project 2061 stresses scientific habits of mind as science process. In contrast to NSES and Project 2061, the three assessment frameworks emphasize science content and process as equally important. New Standards adds four categories of standards related to science process, including scientific thinking, tools and technologies, scientific communication, and scientific investigation. These process standards complement the conceptual understanding standards derived from the content standards in NSES and Project 2061. The 1996 NAEP framework identifies three elements of "knowing and doing science" (conceptual understanding, scientific investigation, and practical reasoning) that cut across three "fields of science" (earth, physical, and life science). TIMSS includes the performance expectations aspect, in addition to the content aspect. Further, the 1996 NAEP and TIMSS assessment frameworks use the matrix of content-process intersections.

Second, there is a difference in the balance of representations or emphases among content standards. NSES and Project 2061 documents give equal importance to all categories of content standards, and do not differentiate the priority of one standard over another (Webb, 1997, pp. 20-21). NSES states that "None of the eight categories of content standards should be eliminated . . . No standards should be eliminated from a category" (NRC, 1996, pp. 11-112). In contrast, three assessment frameworks distinguish the importance by assigning differential weights among categories of content standards. For example, in terms of the number of assessment items, assessment time, and maximum score points, 1996 NAEP (NAGB, 1994, 1996; O'Sullivan, Reese, & Mazzeo, 1997) and TIMSS (Martin & Kelly, 1996; McKnight, Schmidt, & Raizen, 1993) give more emphases on life, physical, and earth and space science than the rest of the

categories of content standards. New Standards maintains the categories of physical science, life science, and earth and space science, but combines the four categories in NSES (science and technology, science in personal and social perspectives, history and nature of science, and unifying concepts and process) into one category called "scientific connections and applications."

Differences among the three assessment frameworks, shown in Table 1, reside partially in the purposes and contexts of the documents. The four categories of science process in New Standards respond to the NSES emphasis on scientific inquiry, and New Standards specifies performance measures for scientific inquiry (NCEE, 1997a, p. 130). Because NAEP tracks the progress in science achievement of U.S. students, it has to maintain the continuity of the assessment framework over the years, while representing the changes at certain times. TIMSS occurred in an international context and had to consider the curricula of all participating countries.

Science Achievement: Synthesis of Current Conceptions

Based on the analysis of commonalities and differences in the views of science achievement among the five sets of documents, an aggregated view of science achievement is presented in this section. The summary is presented in Table 2. Five components of science content and four components of science process emerge from the analysis of these documents. For each component, key indicators are identified, rendering the component more specific and concrete. In this sense, these indicators serve as the operational definition of each component. In addition, similarities and differences in key terms and their meanings across the documents are clarified. Examples of the components and indicators are provided from emerging research and literature in science education.

Table 2

Science Achievement: An Aggregated View from Major Reform Documents

	Components	Indicators	Document Sources
Content	**Physical Science** **Life Science** **Earth and Space Science**	• key concepts and theories • key vocabulary	All
	Science, Mathematics, and Technology		
	Mathematics	• measurement concepts • statistics and probability concepts	Project 2061, TIMSS
	Technology	• engineering and design	All
	Personal and Social Perspectives	• health • population growth • natural resources • environmental quality • safety and hazards	NSES, Project 2061, TIMSS, New Standards
	History and Nature of Science		
	History of science	• historical developments of major discoveries • contributions of diverse cultures	All
	Nature of science	• nature of scientific knowledge • nature of scientific inquiry • the scientific world view	All
	Unifying Themes	• systems • models • constancy and change • evolution and equilibrium • form and function	NSES, Project 2061, NAEP, New Standards
Process	**Scientific Understanding**	• key concepts and theories • relationships among concepts and theories • explanations of natural phenomena • applications to new situations	All
	Scientific Investigation	• a systemic observation, a fair test, or a controlled experiment • scientific tools and equipment	All
	Scientific Communication	• multiple representations • rules of the discourse of science	NSES, Project 2061, TIMSS, New Standards
	Scientific Habits of Mind	• values and attitudes	NSES, Project 2061

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		• thinking skills	

Science Content

The components of science content are generally consistent with the NSES standards (see Table 1). The five components include: (a) physical, life, and earth and space sciences; (b) science, mathematics, and technology; (c) science in personal and social perspectives; (d) history and nature of science; and (e) unifying themes. Each of these components is described below.

Physical, life, and earth and space sciences. All of the documents identify three fields or disciplines of science. NSES defines this category of standards as follows: "Science subject matter focuses on the science facts, concepts, principles, theories, and models that are important for all students to know, understand, and use" (p. 106). Main science topics from these documents are presented in Table 3.

Table 3

Topics in Physical, Life, and Earth and Space Sciences from Major Reform Documents

Fields of Science	NSES (1996)	Project 2061 (1989, 1993)	New Standards (1997)	NAEP (1994, 1996)	
Earth and Space Science	K-4 Properties of earth materials Objects in the sky Changes in the earth and sky 5-8 Structure of the earth system Earth's history Earth in the solar system 9-12 Energy in the earth system Geochemical cycles Origin and evolution of the earth system Origin and evolution of the universe	K-2, 3-5, 6-8, 9-12 The universe The earth Processes that shape the earth	Elementary school (4th) Properties of earth materials Objects in the sky Changes in the earth and sky Middle school (8th) Structure of the earth system Earth's history Earth in the solar system Natural resource management High school (10th) Energy in the earth system Geochemical cycles Origin and evolution of the earth system Origin and evolution of the universe Natural resource management	4th, 8th, 12th Solid earth (lithosphere) Water (hydrosphere) Air (atmosphere) Earth in space	Ag Ea Ea Ea

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Table 3 (Continued)

Fields of Science	NRC (1996)	Project 2061 (1989, 1993)	New Standards (1997)	NAEP (1994, 1996)	
Life Science	K-4 Characteristics of organisms Life cycles of organisms Organisms and environments 5-8 Structure and function in living systems Reproduction and heredity Regulation and behavior Population and ecosystems Diversity and adaptations of organisms 9-12 The cell Molecular basis of heredity Biological evolution Interdependence of organisms Matter, energy, and the organization in living systems Behavior of organisms	K-2, 3-5, 6-8, 9-12 Diversity of life Heredity Cells Interdependence of life Flow of matter and energy Evolution of life Human identity Human development Basic functions Learning Physical health Mental health	Elementary school (4th) Characteristics of organisms Life cycles of organisms Organisms and environments Change over time Middle school (8th) Structure and function in living systems Reproduction and heredity Regulation and behavior Population and ecosystems Evolution, diversity, and adaptation of organisms High school (10th) The cell Molecular basis of heredity Biological evolution Interdependence of organisms Matter, energy, and organization in living systems Behavior of organisms	4th, 8th, 12th Changes and evolution Cells and functions Organisms Ecology	Ag Di Lif Lif Int Hu

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Table 3 (Continued)

Fields of Science	NSES (1996)	Project 2061 (1989, 1993)	New Standards (1997)	NAEP (1994, 1996)	
Physical Science	K-4 Properties of objects and materials Position and motion of objects Light, heat, electricity, and magnetism 5-8 Properties and changes of properties in matter Motions and forces Transfer of energy 9-12 Structure of atoms Structure and properties of matter Chemical reactions Motions and forces Conservation of energy and increase in disorder Interactions of energy and matter	K-2, 3-5, 6-8, 9-12 Structure of matter Energy and transformations Motion Forces of nature	Elementary school (4th) Properties of objects and materials Potion and motion of objects Light, heat, electricity, and magnetism Middle school (8th) Properties and changes of properties in matter Motions and forces Transfer of energy High school (10th) Structure of atoms Structure and properties of matter Chemical reactions Motions and forces Conservation of energy and increase in disorder Interactions of energy and matter	4th, 8th, 12th Matter and its transformations Energy and its transformations Motion	Ag Ma Str En Ph Ch Fo

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Overall consistency exists among the documents for the topics of physical science, including matter, energy, and motions and forces. Although there seems to be some consistency for the topics of earth and space science, including the earth, the solar system, and the universe, the consistency for the topics of life science is less clear. The analysis by topics may be too general to indicate the degree of agreement among these documents. The same topics may include different content, whereas different topics may include similar content. Also, the same topics may be interpreted in different ways at different levels of specificity and at different grade levels.

There is an overall agreement on science topics and content among NSES, Project 2061, and New Standards (AAAS, 1996, 1997; NCEE, 1997a, 1997b, 1997c). The 1996 NAEP and TIMSS frameworks were designed to assess "common denominators" of science topics and content across the states in the U.S. (NAEP) or the participating countries (TIMSS). A more specific analysis of the correspondence among the five sets of documents is beyond the scope of this paper.

Within the context of standards-based and systemic reform, there is a general consensus on the topics and content of physical, life, and earth and space science. U.S. science education has been criticized for being "a mile wide and an inch deep," indicating that the curriculum covers too many topics superficially and does not allow students sufficient time to develop a deep understanding (Schmidt, McKnight, & Raizen, 1997). In the current reform, the focus is on a small number of key topics at greater depth -- the principle of "less is more."

Science vocabulary has traditionally played an important role in science. Science textbooks are often filled with technical terms, sometimes in bold type to capture the attention of readers. Project 2061 emphasizes key vocabulary words to the extent that they enhance the precision and sophistication of understanding, while strongly discouraging the glib use of these words without adequate understanding (e.g., AAAS, 1989, pp. xiv, p. 190; AAAS, 1993, pp. 263, 312):

> Understanding rather than vocabulary should be the main purpose of science teaching. However, unambiguous terminology is also important in scientific communication and -- ultimately -- for understanding. Some technical terms are therefore helpful for everyone, but the number of essential ones is relatively small. If teachers introduce technical terms only as needed to clarify thinking and promote effective communication, then students will gradually build a functional vocabulary. (AAAS, 1989, p. 190)

Science, mathematics, and technology. The integration of science, mathematics, and technology has been a common expectation in current science education reform. Project 2061 (AAAS, 1989) describes their interrelationships, as follows:

> Scientists see patterns in phenomena as making the world understandable; engineers also see them as making the world manipulable. Scientists seek to show that theories fit the data; mathematicians seek to show logical proof of

> abstract connections; engineers seek to demonstrate that designs work. Scientists cannot provide answers to all questions; mathematicians cannot prove all possible connections; engineers cannot design solutions for all problems. (p. 25)

The five sets of documents identify the role of *mathematics* in science learning in different ways (see Table 1). Project 2061 emphasizes mathematics as integral to science, whereas NSES does not include mathematics as a key component of science. The three assessment frameworks emphasize mathematics with varying degrees. Because mathematics is involved in all aspects of science learning, it is difficult to specify its role in science learning. In the framework presented here, two aspects of mathematics related to science are highlighted: (a) measurement concepts and (b) statistics and probability concepts.

Although integration of mathematics and science has been a common expectation in science curriculum and instruction, research on the role of mathematics in science learning and the relationship between science and mathematics learning is limited. Because of this limited information, there is an increasing interest in examining the mathematical components of science learning. For example, the research, "Building bridges between mathematics and science," attempts to integrate mathematical and scientific reasoning in elementary school (Lehrer & Schauble, 1996, 1998). Specifically, teachers develop ways to help students develop mathematical ideas, including spatial visualization, data, and measurements, that can serve as a bridge to scientific reasoning.

All of the documents stress *technology* in science learning. Among many definitions of technology (Raizen, Sellwood, Todd, & Vickers, 1995), these documents consistently use technology to refer to engineering and design. NSES defines technology as design:

> As used in the *Standards*, the central distinguishing characteristic between science and technology is a difference in goal: The goal of science is to understand the natural world, and the goal of technology is to make modifications in the world to meet human needs. Technology as design is included in the Standards as parallel to science as inquiry. (p. 24)

Project 2061 (AAAS, 1989) defines technology as engineering, design, or engineering design interchangeably:

> The component of technology most closely allied to scientific inquiry and mathematical modeling is engineering. In its broadest sense, engineering consists of construing a problem and designing a solution for it. (p. 25)

Technology as engineering and design differs from "instructional technology," including scientific tools, computers, and electronic devices (NRC, 1996, p. 24). Consistent with NSES, the framework proposed here does not include these tools and devices as part of technology; instead, they are considered as part of scientific investigation (to be described later).

Despite its importance in making science relevant and practical in everyday life, technology as engineering and design has been largely ignored in school science (Raizen et al., 1995). However, the situation is changing. The current emphasis on technology is promoted by the Science-Technology-Society curriculum programs that focus on using science for the solution of natural and human-made problems in society (Bybee & DeBoer, 1994). There is a growing interest in engineering and design in science instruction. Design projects are relevant to students' everyday experiences, are intuitively meaningful compared to abstract theoretical constructs, require applications of science concepts in solving complex tasks, and resemble problem solving in real-world situations. Design projects also require alternative solutions to complex problems and involve trade-offs of advantages and disadvantages with each alternative. Some examples include making a boat that maximizes the capacity of carrying a load for the concepts of flotation and buoyancy (Duschl & Petasis, 1995), designing an elbow as a type of lever (Penner, Giles, Lehrer, & Schauble, 1997), and using a model of heat flow in engineering, rather than kinetic molecular theory in physics (Linn & Muilenburg, 1996).

Science in personal and social perspectives. This component is included in all the documents, except for NAEP. NSES and Project 2061 include a broad range of personal and social issues, whereas TIMSS and New Standards have a limited focus on a narrow range of specific issues. Main topics include health, population growth, natural resources, environmental issues, safety, and natural and man-induced hazards.

Throughout the history of science education for the most part of this century, personal and social relevance of science has been considered important, in addition to science knowledge and inquiry (Atkin et al., 1997; Bybee & DeBoer, 1994). However, the relative importance of the personal and social dimension or the disciplinary dimension of science knowledge and inquiry has shifted at different times of science education reform. The current emphasis is promoted by the Science-Technology-Society curriculum programs. NSES and the other documents try to strike a balance in emphasis between these two dimensions.

The current emphasis on science in personal and social perspectives is consistent with the vision of scientific literacy for all students to become educated citizens, rather than for a select few to become scientists. NSES states, "An important purpose of science education is to give students a means to understand and act on personal and social issues" (p. 107). The emphasis is beyond application of knowledge and skills into decision making about personal and social issues. As students investigate such issues, they become involved in exploring alternative, sometimes controversial, points of view that require moral and ethical considerations. The goal is to help students learn to make informed decisions about personal and social matters based on sound knowledge of science.

The emphasis on personal and social perspectives of science can provide opportunities for students to appreciate both the contributions and limitations of science in dealing with social phenomena, to consider multiple perspectives in making personal decisions, to judge the impact and consequences of decisions, and to distinguish scientific knowledge and evidence from personal beliefs and opinions. Simple examples of science in personal and social perspectives include the choices between paper and plastic bags or between disposable and cloth diapers, each with benefits and negative impacts on production costs and the environment. Other examples

include the greenhouse effect, global warming, cloning, and nuclear energy, as well as many health and environmental issues.

History and nature of science. All of the documents emphasize the history and nature of science. Although the two are closely related, each is described below.

With regard to the *history of science,* the historical development of major discoveries in modern science is emphasized in all the documents. This historical development is defined in terms of the tradition of Western science since the Copernican revolution. The contributions of non-Western cultures to science and technology are mentioned in NSES and Project 2061, but this issue is not included in the other documents.

Both NSES and Project 2061 define Western science as the proper domain of science. *Science for All Americans* (AAAS, 1989) describes the history of science as follows:

> The recommendations in this chapter focus on the development of science, mathematics, and technology in Western cultures, but not on how that development drew on ideas from earlier Egyptian, Chinese, Greek, and Arabic cultures. The sciences accounted for in this book are largely part of a tradition of thought that happened to develop in Europe during the last 500 years -- a tradition to which people from all cultures contribute today. (p. 136)

NSES describes the contributions of all cultures to science and technology. These contributions are recognized in terms of technological inventions to solve human problems and needs, rather than the traditions of thought that define the nature and practice of science to understand and explain natural phenomena. NSES states historical perspectives in science as follows:

> Modern science began to evolve rapidly in Europe several hundred years ago. During the past two centuries it has contributed significantly to the industrialization of Western and non-Western cultures. However, other, non-European cultures have developed scientific ideas and solved human problems through technology. (p. 201)

In addition to major scientific discoveries in modern science and the contributions of all cultures, there are other important reasons for emphasizing historical perspectives in science. First, the historical accounts demonstrate science as a human endeavor, which is "influenced by societal, cultural, and personal beliefs and ways of viewing the world. Science is not separate from society, but rather science is a part of society" (NRC, 1996, p. 201). Second, the historical accounts also illustrate how the nature and practice of science has evolved over the past several hundred years (AAAS, 1989, pp. 135-153). Third, the evolution of scientific ideas in history provide insights into students' naive or incorrect conceptions about natural phenomena, which is a common topic in research on conceptual change in science (see the review in AAAS, 1993). Finally, acknowledgments of contributions of all cultures in science and technology can be an incentive for students from diverse backgrounds, who have traditionally been under-represented in science and technology, to participate in these areas (Rodríguez, 1997a).

The *nature of science* involves several aspects, including the nature of scientific knowledge, the nature of scientific inquiry, and the scientific world view. The nature of scientific knowledge and inquiry is emphasized in all of the documents with varying degrees. NSES focuses more on inquiry; Project 2061 focuses more on scientific knowledge; and the three assessment frameworks include both. The scientific world view is stressed only in Project 2061 (AAAS, 1989, 1993).

The nature of scientific knowledge involves how the knowledge is generated, tested, disputed, and justified. Scientists across disciplines share a general agreement on what constitutes scientific knowledge (AAAS, 1989, pp. 5-13; NRC, 1996, pp. 171, 201). The credibility and power of a scientific theory depends on its ability to explain and predict a wide range of natural phenomena and show relationships among these phenomena. Scientific knowledge is subject to change and always under dispute and contention. Yet, most scientific knowledge has become stable and durable through numerous verifications across settings and over time. Even a new theory generally involves modifications, rather than complete rejection, of existing ideas.

Scientists also share a general agreement on what constitutes a scientifically valid inquiry (AAAS, 1989, pp. 5-9; NRC, 1996, p. 23). Scientific inquiry involves a rigorous process of observation, experimentation, and validation, and generates explanations based on evidence, reasoning, and logic. Contrary to what is generally known as "the scientific method" with a set of procedures, there is no fixed set of steps to follow in scientific inquiry.

The scientific world view indicates that science is a way of knowing that distinguishes itself from other ways of knowing and from other bodies of knowledge (AAAS, 1989, pp. 3-5; NRC, 1996, p. 201). Science seeks to understand how the world works through particular modes of observation, experimentation, and validation, described earlier. Project 2061 (AAAS, 1989) states, "There are many matters that cannot usefully be examined in a scientific way. There are, for instance, beliefs that -- by their very nature -- cannot be proved or disproved (such as the existence of supernatural powers and beings, or the true purposes of life)" (p. 4). NSES also states, "Explanations on how the natural world changes based on myths, personal beliefs, religious values, mystical inspiration, superstition, or authority may be personally useful and socially relevant, but they are not scientific" (201).

Students' understanding of the nature of scientific knowledge and inquiry has been investigated rather extensively (e.g., Ryan & Aikenhead, 1992; Songer & Linn, 1991). Because elementary students have not had enough experience to develop a notion of the nature of science and because it is difficult to gather and interpret their responses, most of the research has been conducted with middle and high school students. The students often have difficulty understanding the nature of scientific knowledge and inquiry. They see science as an accumulation of factual knowledge that is based solely on data and objective observations, but fail to consider the likelihood of biased observations and interpretations (Carey, 1985; Carey & Smith, 1993). Many also consider scientific knowledge as either absolutely true or always tentative and subject to change. In addition, they have difficulty differentiating between a theory and evidence, between description and interpretation of evidence, and between informed reasons and personal opinions (Kitchener & King, 1981; Kuhn, 1993, 1997). In general, students have

difficulty understanding science as a human endeavor to construct knowledge that is increasingly closer approximations to truth in understanding and explaining how the world works.

The scientific world view is a topic that has recently become an important area of research. The research indicates that although the distinction between the scientific world view and alternative views may be relatively straightforward to educated adults, children's world views involve a complex interaction of personal and supernatural beliefs with scientific understanding (Cobern, 1991; Hewson, 1988; Lee, in press; Loving, 1997). In addition to such developmental trends, the scientific world view is sometimes incompatible with the norms and values of diverse cultures which tend to include spiritual and supernatural forces (Hewson, 1988; Lee, in press). This presents greater challenges in developing the scientific world view for students from diverse cultures and languages than for mainstream students.

Unifying themes. Unifying themes are emphasized in all the documents, except for TIMSS. Unifying themes indicate "big ideas" or "powerful ideas" that transcend a range of basic concepts and processes in science and technology (NSES) or in science, mathematics, and technology (Project 2061). Project 2061 states, "Some important themes pervade science, mathematics, and technology . . . They are ideas that transcend disciplinary boundaries and prove fruitful in explanation, in theory, in observation, and in design" (AAAS, 1989, p. 155). Based on the NSES and Project 2061 documents, the framework here identifies five unifying themes, including systems, models, constancy and change, evolution and equilibrium, and form and function.

Research on unifying themes has been conducted for some time. Studies are available in areas, including: (a) a system, sub-systems, and their relationships, e.g., the water cycle, air pressure, air masses, and fronts as sub-systems of the weather system; (b) the explanatory role of models for understanding and explaining natural phenomena, e.g., models of molecular and atomic structures, models of the solar system; (c) patterns of changes over time or across settings, e.g., changes in trends, cycles, or irregular patterns; (d) evolution and equilibrium, e.g., changes and constancy in ecology or species, and (e) form and function, e.g., forms and functions of biological organs, trade-offs between forms (beauty) and functions (utility) of design projects.

Although the research has identified learning difficulties with unifying themes commonly experienced by students, there are limitations in the existing literature. One limitation is the restriction of research to specific tasks within a narrowly defined science area or a limited set of natural phenomena, rather than students' understanding of unifying themes across science disciplines or a range of natural phenomena. Another limitation is the focus of research on separate aspects of student abilities, such as observation, explanation, theory, or design, rather than the combination of these abilities. For unifying themes to be truly big ideas, they need to be examined across disciplinary boundaries, a range of natural phenomena, and a spectrum of student abilities.

Science Process

Science process indicates what students should be able to do with the components of science content. Science process is not independent of science content; instead, science process cuts across science content. The four components of science process includes: (a) scientific understanding; (b) scientific investigation; (c) scientific communication; and (d) habits of mind (see Table 2).

Scientific understanding. Scientific understanding refers to the knowledge and understanding of key concepts and theories, and their applications to explain natural phenomena. This is consistent with "conceptual understanding" in New Standards; "conceptual understanding" in NAEP, and "understanding" in TIMSS. NSES defines scientific knowledge and understanding as follows:

> Scientific knowledge refers to facts, concepts, principles, laws, theories, and models and can be used in many ways. Understanding science requires that an individual integrate a complex structure of many types of knowledge, including the ideas of science, relationships between ideas, reasons for these relationships, ways to use ideas to explain and predict other natural phenomena, and ways to apply them to many events. (p. 23)

Based on the NSES definition and science education research (e.g., Kennedy, 1998; Secada, 1997), scientific understanding includes several distinct abilities: (a) acquisition of key concepts and theories in science disciplines, such as those specified in major reform documents (see Table 3); (b) construction of relationships between and among concepts and theories within a science discipline, for example, relationships between heat energy and changes of states of matter in physical science; (c) construction of relationships among concepts and theories across science disciplines, for example, molecular and atomic theories across physical changes, chemical changes, and human biological systems; (d) use of concepts and theories to explain and predict natural phenomena; and (e) applications of concepts and theories to new, real-world situations.

Prior knowledge and personal experience play key roles in acquiring new knowledge and developing conceptual understanding (Driver et al., 1994; Posner, Strike, Hewson, & Gertzog, 1982). Learning and understanding in science occurs when students successfully integrate new information with their prior experiences in ways that are both scientifically accurate and personally meaningful. Because students are always building new relationships among their ideas and restructuring those ideas, their understanding is dynamic, changing, and growing. Students' understanding of science concepts has been studied extensively since the late 1970s (for review of the research, see chapter 15 in AAAS, 1993). Cognitive scientists or conceptual change researchers have examined students' conceptions of natural phenomena using in-depth interviews. The research has revealed that students usually have ideas about how the world works based on common-sense experiences and that these misunderstandings or misconceptions remain highly resistant to change even after instruction. Despite this extensive body of literature,

only a small number of science concepts have been investigated, and the studies are unevenly distributed across science fields.

Scientific investigation. The five sets of documents use two related terms, "scientific inquiry" and "scientific investigation" (see Table 1). NSES and Project 2061 use inquiry, whereas New Standards, 1996 NAEP, and TIMSS use investigation. The framework proposed here uses scientific investigation as it is used in New Standards, 1996 NAEP, and TIMSS. Distinctions between these two terms and meanings are made next.

Both NSES and Project 2061 use scientific inquiry in a broad sense. NSES (NRC, 1996) provides a comprehensive definition:

> Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. (p. 23)

NSES provides an equally comprehensive description of what scientific inquiry involves:

> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. (p. 23)

In this broad view, NSES emphasizes inquiry as an overarching goal of science education through which students develop the knowledge and abilities of other components of science achievement (NRC, 1996, p. 105). At the same time, NSES identifies inquiry as one component of science achievement, consisting of both "the ability to conduct inquiry" (process) and "understanding about scientific inquiry" (content) (p. 105).

In contrast to NSES and Project 2061, New Standards, 1996 NAEP, and TIMSS use scientific investigation in a more limited and specific way. These documents consider scientific investigation as a systemic observation, a "fair" test ("a test in which only one variable at a time is changed" in NRC, 1996, p. 122), or a controlled experiment. During scientific investigation, students formulate questions, devise plans to explore the questions, make and revise hypotheses, collect and analyze data, interpret data, generate explanations, and draw conclusions. Students also use appropriate tools and equipment for conducting investigation.

Scientific investigations occur at different developmental levels (AAAS, 1993; NRC, 1996). Elementary students can do a systemic observation or a fair test. However, they have difficulty designing and conducting a carefully controlled experiment. They also have difficulty giving explanations based on evidentiary criteria, models, or cause and effect relationships. At

the middle school level, students become more systemic and sophisticated in conducting investigations. They develop an understanding of what constitutes a good experiment, although they have difficulty controlling variables systematically. They can also make distinctions between descriptions and explanations and provide explanations in terms of causality or models. High school students can conduct the entire process of scientific investigations, provide logical explanations based on evidence, make predictions about complex phenomena, and test alternative ideas and approaches.

Scientific tools and equipment play important roles in scientific investigations. In early grades, students develop skills in using simple tools, such as rulers to measure the length and height of objects, scales and balances to measure weight and force, thermometers to measure temperature, watches to measure time, and magnifiers and microscopes to measure finer details of objects and organisms. As students gain experience, they learn to use tools and equipment for data collection, storage and retrieval of information, data analysis and pattern recognition, and organization and display of results. Computers and electronic devices provide rich and extensive data sources, such as access to real time data as natural phenomena and events unfold.

Scientific communication. The roles of communication and discourse have been increasingly emphasized in science reform documents, as well as in science education research (Holliday, Yore, & Alverman, 1994; Lemke, 1990; Palincsar, Anderson, & David, 1993). Scientific communication is emphasized in New Standards and TIMSS. Although NSES and Project 2061 do not identify process standards, including scientific communication, the importance of scientific communication is stressed in the text of the documents. NSES (NRC, 1996) emphasizes, "[Teachers] structure and facilitate ongoing formal and informal discussion based on a shared understanding of rules of scientific discourse. A fundamental aspect of a community of learners is communication" (p. 50). In the framework presented here, two aspects of scientific communication are highlighted: multiple representations and rules of scientific discourse.

In the process of knowing and doing science, students develop and organize their knowledge and understanding through communication. They can demonstrate their knowledge and understanding using multiple representational formats, including oral communication, writing, drawings, charts, diagrams, tables, graphs, figures, and concept maps. Representational fluency also includes the use and interpretation of mathematical symbols and models, computer graphics and simulations, and spreadsheets.

Children in the elementary grades may have difficulty with multiple representations. Until recently, much of the communication about science has been done through reading and writing, as opposed to oral communication (Yore, Holliday, & Alverman, 1994). With the growing emphasis on younger children and less literate students, speaking (Gallas, 1995) or using pictures and drawings (Lee & Fradd, 1996a) can be important means of communication. Because scientific discourse stresses explicit communication in written or symbolic forms, students gradually learn to present their understanding in concise and powerful representational formats.

As students engage in formal and informal discussion of science, they develop an understanding of the rules of scientific discourse (Anderson, Holland, & Palincsar, 1997; Palincsar, Anderson, & David, 1993). They learn how to explain, analyze, debate, justify, argue, defend, critique, and challenge the work of other students, as well as their own work. While engaging in scientific arguments, students use facts, evidence, logic, and reasoning to support or dispute conclusions (Rosebery, Warren, & Conant, 1992). Students gradually develop abilities to communicate clearly, construct reasoned arguments, and respond logically to critical comments.

Scientific habits of mind. This component is emphasized in recent reform, especially in Project 2061. Project 2061 defines scientific habits of mind in terms of certain values, attitudes, and skills associated with science, mathematics, and technology (AAAS, 1989, chapter 12 and pp. 189-192). Although NSES uses the term "habits of mind" only once (p. 170) throughout its 100 pages on content standards, the document emphasizes scientific values, attitudes, and skills throughout the text. Based on Project 2061 and NSES, scientific habits of mind in the framework here include: (a) scientific values and attitudes and (b) thinking skills.

Of scientific values and attitudes (AAAS, 1989, chapter 12 and pp. 189-193; NRC, 1996, p. 50-51), some are generally shared in society and highly regarded as basic human qualities, including curiosity, interest, insight, energy, diligence, persistence, intellectual honesty, and creativity. Others are central to science, including critical and independent thinking, tolerance of ambiguity or uncertainty, openness to new ideas, skepticism, empirical verification, arguments based on logic and evidence, and questioning rather than deferring to authority. In addition to independent thinking and performance, scientific values and attitudes also include teamwork, collaboration, and shared responsibility for learning with others in a science community. Scientific habits of mind also include thinking skills, such as heuristics of number sense and quantitative reasoning, logical skills, and metacognition in reflecting and self-assessing one's own learning process and performance.

The topic of scientific habits of mind is a new area of emphasis in recent reform. Attitudinal variables in science, such as interest, curiosity, and affect, have been studied extensively. But this research is generally based on students' self-reports on questionnaires, rather than observations of students' behavior or dispositions to provide more accurate and specific information. The scientific values and attitudes central to science, such as openness to new ideas, skepticism, questioning, and tolerance of ambiguity, have not been studied (for an exception, see Goldenberg, in press, in the case of mathematics education). These values and attitudes may not occur with young students until they have had sufficient experience in learning science in middle and high school years. Considering that scientific values and attitudes generally reflect and respond to the norms and practices of the western society in which modern science has evolved, these values and attitudes would pose greater difficulties to students from diverse cultures and languages than students from the mainstream (Lee & Fradd, 1996b).

An Aggregated View of Science Achievement

In summary, based on the analysis of commonalities and differences among major reform documents, an aggregated view of science achievement is described in this section and presented in Table 2. Several conclusions are drawn. First, science achievement is conceived in terms of

science content and science process, and the components of science process cut across the components of science content. Second, terms and meanings are sometimes used differently among these documents, and there is a need to develop a common language. Third, the components of science achievement overlap and relate to one another. Despite such an overlap, understanding the role that each component plays provides insight into its unique contributions as well as its interactions with other components. Finally, a definition of science achievement and identification of its components based on major reform documents provides a guideline for science assessment as well as science teaching and learning.

Standards-Based Assessment in Large Education Systems

At the heart of standards-based reform is the alignment of assessment with content standards. The National Academy of Education panel report states: "The intention of standards-based reform is to set higher standards for all students . . . New kinds of assessment reflecting these new standards are seen as instrumental in effecting the reform" (McLaughlin, Shepard, & O'Day, 1995, p. 52). Regardless of how challenging and rigorous the content standards are, if all the learning outcomes are not assessed, "teachers and students likely will redefine their expectations for learning science only to the outcomes that are assessed" (NRC, 1996, p. 82). In this section, implications of the analysis of science achievement for assessment in large education systems are described, particularly focusing on alignment of assessment with content standards.

Specification of Content Standards into Assessment

Aligning assessment with content standards is a complex task (Webb, 1997). The first step in standards-based assessment is to develop an assessment framework that is derived from content standards. The content standards should be stated as specific learning outcomes that can be measured. Then, based on the assessment framework, assessment specifications are designed -- "specific aspects, limits, and boundary conditions" on the domains of knowledge and abilities to be assessed (Webb, 1997, p. 37). For 1996 NAEP, the assessment framework is described in NAGB (1996) and the assessment specifications in NAGB (1994). For TIMSS, the assessment framework is described in Robitallie et al. (1993) and the assessment specifications in McKnight, Schmidt and Raizen (1993). In New Standards, a set of performance descriptions for each performance standard serves as assessment specifications (NCEE, 1997a, 1997b, 1997c).

Once assessment frameworks and specifications are designed, the next step in standards-based assessment is to develop assessment activities. A general concern with NSES is that the content standards are too broad and general to guide assessment activities. Even performance standards, such as New Standards, "are not specified well enough for purposes of test development. They do not adequately guide the concrete decisions that need to be made on what is to be measured, how it is to be measured, and what specific tasks and criteria will be used" (Wiley, cited in National Center for Research on Evaluation, Standards, and Student Testing, 1997, p. 5). An extensive knowledge gap exists in specifying the standards to develop assessment activities (Massell, 1994; McLaughlin, Shepard, & O'Day, 1995).

Forms of Assessment

To measure the kinds of knowledge and abilities expected in content standards, appropriate forms of assessment are required. There should be a match between what is to be measured and how best to measure it. Traditionally, large-scale assessments tend to focus on basic knowledge and skills and use restricted response forms, most commonly the multiple choice format (McLaughlin, Shepard, & O'Day, 1995). In contrast, higher-level thinking and complex abilities in science content standards require new forms of assessment (National Center for Research on Evaluation, Standards, and Testing, 1997). Although the increasing use of alternative assessments indicate current efforts, these assessments present new challenges, as described next.

Large-scale assessments, such as NAEP and TIMSS, have changed significantly in recent years. Traditionally, NAEP science assessments used mostly multiple choice items with some open-ended items. The Second International Science Study [SISS] also used multiple choice items exclusively (International Association for the Evaluation of Educational Achievement, 1988). In response to the current emphasis on scientific understanding, 1996 NAEP and TIMSS included open-ended, free-response items (including both short-answer and extended-response items) as well as multiple choice items. In addition, along with the emphasis on scientific investigation and communication, 1996 NAEP for the first time included performance exercises (also called hands-on tasks) (O'Sullivan, Reese, & Mazzeo, 1997, p. 42). TIMSS used performance tasks (also called hands-on activities) with a sub-sample of students.

In performance exercises or tasks in 1996 NAEP and TIMSS, students manipulate materials, conduct scientific investigations, and communicate their observations and results. Despite its critical importance in standards-based assessment, performance measures in large-scale assessments, such as NAEP and TIMSS, present limitations. First, because of the need for standardization, performance exercises or tasks are provided for students along with the materials to use, procedures to follow, graphs or tables to report the data, and questions to answer. This standard procedure does not allow students to ask their own questions, design and conduct investigations, and communicate observations or results in their own ways. NAEP also cautions that performance tasks often become "follow-the-instructions" questions, rather than higher-level thinking in new contexts or applications to novel situations (NAGB, 1996, pp. 31-33). Second, performance exercises or tasks in 1996 NAEP and TIMSS are completed within limited time in one setting. This constraint does not allow scientific investigations of natural events as an on-going process. These limitations are inherent in external, large-scale assessments.

New Standards focuses on performance assessments that teachers can use in the classroom, as well as states and urban school districts can use in systemic reform. As part of science instruction in the classroom, New Standards does not have the constraints of NAEP or TIMSS. The samples of student work included in the New Standards documents (NCEE, 1997a, 1997b, 1997c) indicate that the assessment system effectively measures many components of science achievement. These components include scientific investigation and communication, as well as understanding of key concepts in three fields of science and unifying themes across the

fields. In contrast, the assessment system rarely addresses technology, science in personal and social perspectives, history and nature of science, and scientific habits of mind.

The discussion here indicates inherent difficulties in the assessment of higher-level thinking and complex abilities in large-scale projects. First, some components of science achievement are difficult to assess. For example, it is difficult to operationalize abstract constructs, such as scientific habits of mind, in concrete and specific terms. Even after operational definitions are obtained, it is difficult to develop standardized procedures of assessment, for example, science in personal and social perspectives. There is a concern that in the process of making these components measurable, assessments may become trivialized and their importance become minimized.

Second, certain components of science achievement can not be assessed on demand. For example, scientific investigation involves students' asking their own question and finding answers on their own as an on-going process. Scientific habits of mind occur naturally as students engage in science tasks. It is difficult to assess students' scientific investigation or habits of mind on demand within the confines of assessment settings.

Finally, large-scale assessment generally involves written forms. Certain types of knowledge and abilities may require different forms of assessment. For example, assessment of technology (i.e., engineering and design) can be done by constructing actual products. Assessment of scientific habits of mind can be done informally as teachers observe cues of students' dispositions (Webb, 1997, p. 22). Abilities to engage in scientific discourse can be observed as students engage in communication with others in group settings. Although a range of assessment forms can be utilized in classroom assessment, including observations, products, interviews, and portfolios, it is difficult to incorporate these forms in large-scale assessments.

There is a clear indication that large-scale assessment projects, especially NAEP and TIMSS, influence state-level assessments (George & Van Horne, 1996; Glaser & Linn, 1997; National Center for Research on Evaluation, Standards, and Student Testing, 1997). NAEP science assessments have been used for state-level results since 1990. States also have expressed an interest in creating linkages that allow the comparisons of state assessments with national and state-level NAEP (Glaser & Linn, 1997). Some states incorporate released items from NAEP and TIMSS in their assessment programs, compare their achievement results with those of other states or countries, and analyze their science curricular and teaching practices (Champagne, 1997). As systemic reform continues and is likely to intensify (American Federation of Teachers, 1997; Council of Chief State School Officers, 1997; McLaughlin, Shepard, & O'Day, 1995), the central role of assessment in evaluating the impact of standards-based and systemic reform on student achievement will increase at national and state levels.

Equity in Large Education Systems

Educational equity is emphasized, along with high academic standards, in systemic reform. The focus on equity is an attempt to address significant achievement gaps among students from diverse backgrounds in terms of ethnicity, language, gender, disabilities, and socio-economic levels. Standards-setting is an important first step in achieving equity because

educators now know the expectations for all students. Without resources and opportunities, however, setting high academic standards may pose additional challenges and learning difficulties to these students (Kahle, 1997; Porter, 1995). There is a great concern that "lack of support in reaching high standards will further victimize students already harmed by gross inequities in the educational system" (McLaughlin, Shepard, & O'Day, 1995, p. 68).

To start the discussion on equity, its meaning needs to be considered. Equity is defined in many different ways, and these definitions are often inconsistent and even contradictory (Lynch et al., 1996; Secada, 1994). Within the scope of this paper on science achievement, the discussion here is limited to equity issues in relation to content standards and standards-based assessment in large education systems. As the discussion indicates, implications of the analysis of science achievement for equity present tensions and dilemmas, but the existing research and literature is limited and insufficient to resolve these tensions and dilemmas.

Equity in Relation to Content Standards

Both NSES and Project 2061 emphasize equity along with excellence as a dual goal of science education reform. NSES (NRC, 1996) highlights equity as the first of its four guiding principles: "*Science is for all students.* This principle is one of equity and excellence" (p. 20, original emphasis). The premise of Project 2061 is equity, as reflected in the title of the document, *Science for All Americans* (1989). What counts as science and what should be taught in school science as presented in these documents, however, are often incompatible with ways of knowing and thinking by diverse students. These issues are addressed next.

What counts as science? Equity concerns in science achievement begin with the basic notion of "what counts as science?" and "what should be taught in school science?" (Lee, 1997). As described about the history and nature of science in the previous section, NSES and Project 2061 define Western science as the proper domain of science. NSES recognizes the contributions of diverse cultures for technological inventions, but not in terms of the tradition of science to understand and explain natural phenomena.

Recently, alternative views of science have been advocated by scholars in emerging areas of multicultural education, feminism, and sociology and philosophy of science (Atwater & Riley, 1993; Eisenhart, Finkel, & Marion, 1996; Hodson, 1993; Matthews, 1994; Rodríguez, 1997a; Stanley & Brickhouse, 1994). These scholars raise issues of power and marginalization of non-Western groups, and challenge the basic notion of science and science achievement as traditionally defined. They highlight scientific and technological traditions of non-Western cultures and argue for more inclusive views of science.

As this debate suggests, what counts as science raises a serious question about equity in science achievement. The Western view of science as currently practiced in the science community and taught in school science presents "high status knowledge," and every student should have access to such knowledge. On the one hand, the emphasis on the high status knowledge without consideration of diverse views about the nature of science may make science less accessible, relevant, or meaningful for some students, particularly those who have traditionally been bypassed in science education. On the other hand, the emphasis on diverse

views that are culturally significant but marginally important as science topics in the science community and in school science may not promote equitable outcomes. There needs to be recognition of the views and contributions of diverse cultures in science and technology in defining what counts as science and what should be taught in school science. This tension remains unresolved.

Ways of knowing and thinking by diverse students. In considering equity in science achievement, it is important to examine the extent to which the nature of science is compatible or incompatible with the background knowledge and experiences of students from diverse backgrounds (Atwater, 1994; Lee & Fradd, 1998; Lee, Fradd, & Sutman, 1995). The emerging, although limited, body of research indicates that students from diverse backgrounds bring with them their own ways of looking at the world that are representative of their environments and personal experiences. Their ways of knowing and thinking may or may not be compatible with the nature of science or the way science is generally taught in science class. A few examples, below, illustrate the differences between the nature of science as defined in content standards and diverse views of science.

For example, the emphasis on "scientific inquiry into authentic questions generated from student experiences" (NRC, 1996, p. 31) may pose challenges for students from cultures emphasizing teachers' authority of telling and directing students, rather than promoting students' exploration or alternative solutions (Atwater, 1994; Lee & Fradd, 1998). Because inquiry is not part of their cultural experiences, the students need to be explicitly taught how to do inquiry as they learn to ask their own questions and find answers on their own. As the students develop the abilities to investigate and explore in the science classroom, however, they may recognize conflicts between their school experiences and home expectations for authority. The tension between science knowledge in school and everyday knowledge at home can present learning difficulties to these students.

Cultivation of scientific habits of mind can also pose difficulties to students from diverse cultures and languages. Although some scientific values and attitudes are found in most cultures, others are characteristic of Western science, such as thinking critically and independently, using empirical criteria, making arguments based on evidence and logic, questioning, skepticism, openly criticizing, and tolerating ambiguity. These values and attitudes may be incongruent with the norms of diverse cultures that favor cooperation, social and emotional support, and consensus building. Enabling these students to acquire scientific values and attitudes, while retaining their own cultural norms, requires careful consideration. Using the notion of "border crossing," students have more difficulties crossing the cultural boundaries between their everyday world and the world of science when the discrepancies are greater (Aikenhead, 1996; O'Loughlin, 1992). Faced with challenges in border crossing, some students from diverse backgrounds may become alienated from science or even actively resist learning science. These students develop habits of mind that are opposite of scientific habits of mind.

This discussion about differences between the nature of science as presented in content standards and various ways of knowing and thinking with diverse students raises an important question about equity in science achievement (Atwater, 1994; Lee & Fradd, 1998). On the one hand, in order to promote science achievement, it is important to relate the nature of science to

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the students' background knowledge and experience based on their culture, language, gender, and abilities. On the other hand, by providing information for each specific group, there is a danger of creating stereotypes for the group and also masking generalities across groups.

Equity in Relation to Standards-Based Assessment

Equity consideration in assessment begins and ends with achievement results among diverse groups of students. In the U.S., there are achievement gaps among ethnic, socio-economic, and gender groups (e.g., National Center for Education Statistics, 1992; National Science Foundation, 1994; O'Sullivan, Reese, & Mazzeo, 1997). Beyond this general information, there is limited information about disaggregation of achievement results for gender-by-ethnic groups, or sub-groups within an ethnic group (Rodríguez, 1997b).

There is also limited information about specific populations, such as students with disabilities and limited English proficient students because these students are often exempted from state and district assessments used for accountability (August & Hakuta, 1997; McLaughlin, Shepard, O'Day, 1995). Recently, large-scale assessments tend to include more students with disabilities and limited English proficient students (George & Van Horne, 1996; Glaser & Linn, 1997). For example, on the basis of the inclusion criteria to assess "the achievement of *all* students at a given grade or age," 1996 NAEP included students with disabilities and limited English proficient students (O'Sullivan, Reese, & Mazzeo, 1997, p. 55, original emphasis).

When students with special needs participate in assessments, accommodations are made to ensure that the students can demonstrate their knowledge and abilities accurately. For example, 1996 NAEP offered various assessment accommodations for students with disabilities and limited English proficient students. These accommodations included one-on-one testing, small group testing, extended time, oral reading of directions, signing of directions, use of magnifying equipment, use of an individual to record answers, enlarged versions of test booklets, a Spanish/English glossary of science terms, and bilingual dictionaries (O'Sullivan, Reese, & Mazzeo, 1997). With certain accommodations (e.g., dictate responses), students with learning disabilities outscored regular students in state-wide performance assessment (Koretz, 1997). Assessment accommodations, however, raise questions about the validity of achievement results and the comparability of these results to results obtained under the condition without accommodations.

Although limited English proficient students are more likely to be assessed than students with disabilities, limited English proficient students are less likely to be given accommodations (National Center for Research on Evaluation, Standards, and Testing, 1997). Assessments for limited English proficient students need to be done in the language of instruction, with special assistance in their first language (August & Hakuta, 1997; Shaw, 1997). This accommodation raises a question about the validity of results (Glaser & Linn, 1997). Even on bilingual versions, it would be difficult to distinguish the students' science achievement from their English language proficiency and general literacy in the first language (McLaughlin, Shepard, & O'Day, 1995; Ruiz-Primo & Shavelson, 1996).

Science assessment between standardized forms and alternative forms of assessment has been a topic of debate. Critics of standardized tests charge that these tests are biased in terms of ethnicity, gender, and social class. They argue that standardized tests generally reflect the mainstream culture, contain content bias, incorporate linguistic and cultural bias, and fail to include diverse student populations in the norming process (Darling-Hammond, 1994; Garcia & Pearson, 1994; Supovitz & Brennan, 1997). In an effort to promote equity in assessment, many educators advocate alternative forms of assessment (Darling-Hammond, 1994; Garcia & Pearson, 1994). They claim that alternative assessments provide diverse students with flexible and multiple types of assessment settings, allow the students to participate in assessment activities to be consistent with their cultural preferences, and enable the students to communicate ideas in multiple ways that may not occur in a particular standard format. The relative equity of standardized tests and alternative assessments, however, indicates mixed results with ethnic, socio-economic, and gender groups (see Supovitz & Brennan, 1997 in language arts). In addition, the more flexible and varied assessment activities and settings are, the more difficult it becomes to incorporate them in large-scale assessments.

Science assessment based on rigorous content standards presents both promises and fears with diverse student groups (see the discussion in Lynch et al., 1996; McLaughlin, Shepard, & O'Day, 1995; Ruiz-Primo & Shavelson, 1996; Shaw, 1997). Proponents claim that achievement gaps among ethnic, socio-economic, and gender groups may narrow because standards-based assessments focus on meaning and relevance, rather than discrete knowledge from textbooks. They suggest that authentic tasks drawn from the students' real-life situations motivate and enhance their performance. Skeptics, on the other hand, argue that standards-based assessment may widen the achievement gaps because open-ended tasks and application of knowledge to novel situations may differentially favor students with many opportunities in science-rich environments of home and community over those lacking such opportunities. The skeptics suggest that assessment tasks based on the content and experiences within the classroom are more fair than those requiring knowledge and abilities in novel situations. Empirical evidence to test each of the two positions is limited.

Conclusions and Discussion

This paper reviews and analyzes the conceptions of science achievement in major reform documents, including those on content standards (NSES and Project 2061), performance standards (New Standards), and large-scale assessment frameworks (1996 NAEP and TIMSS). Analysis of commonalities and differences in the conceptions of science achievement in these documents leads to two key conclusions. First, there is an overall agreement on the conceptions of science achievement among the documents. The documents define science achievement in a comprehensive manner, including concepts and theories in physical, life, and earth and space science; scientific inquiry or investigation; science with mathematics and technology; science in personal and social perspectives; nature and history of science; unifying concepts or common themes; and scientific habits of mind. Second, there are some notable differences in the conceptions of science achievement among the documents. These differences are partially due to different contexts and purposes of the documents.

Based on the synthesis of the conceptions of science achievement in these documents, the paper presents an aggregated view of science achievement. Science achievement is conceived in terms of science content and process. The components of science content include: (a) concepts and theories in physical, life, and earth and space science; (b) science, mathematics, and technology; (c) science in personal and social perspectives; (d) history and nature of science; and (e) unifying themes. The components of science process include: (a) scientific understanding; (b) scientific investigation; (c) scientific communication; and (d) scientific habits of mind. The components of science process cut across and intersect with the components of science content.

The paper considers the implications of the aggregated view of science achievement for large-scale assessments. The alignment of assessment with content standards is an essential, but difficult and complex, task. Specifying the content standards into assessment frameworks and assessment activities is not straightforward. To measure higher-level thinking and complex abilities emphasized in the content standards, new forms of assessment are required. In large-scale assessments, some components of science achievement present challenges because it is difficult to operationalize them in concrete terms, to develop standardized procedures, to administer on-demand assessment, or to use multiple forms of assessment (e.g., observations, interviews, products) in addition to written forms. As a result, these components of science achievement may be left out in assessments.

New Standards, 1996 NAEP, and TIMSS present significant innovations in large-scale assessments. All three projects developed assessment frameworks that were generally aligned with science content standards. They also used alternative forms of assessment that broke from the restricted multiple choice format traditionally used in large-scale assessments. The 1996 NAEP and TIMSS used performance tasks and open-ended response items as well as multiple choice items. New Standards focuses specifically on performance assessment . Despite such innovations, these projects also indicate challenges and limitations in assessing high academic standards in large-scale assessments. The innovations and limitations will provide valuable information for developing large-scale assessments in standards-based and systemic reform (Suter, 1994).

Finally, the paper considers the implications of the aggregated view of science achievement for equity. Although major reform documents emphasize educational equity, there are tensions and dilemmas in considering equity related to science content standards and standards-based assessment. In defining what counts as science and what should be taught in school science, there is a tension between the Western view of science as represented in NSES and Project 2061 and views of science in diverse cultures. The nature of science in the Western view is often incompatible with ways of knowing and thinking in diverse cultures. In addition, the relative equity of standardized forms and alternative forms of assessment is under consideration. The equity in assessing rigorous content standards beyond the background knowledge and experiences of students who have limited science opportunities is also under consideration.

In closure, major reform documents in science education consistently emphasize high achievement for all students. The available knowledge about assessment and equity, however, is limited. The difficulties with large-scale assessments are conceptual and practical, in terms of

how to do the assessment within the confines of assessment settings. The difficulties with educational equity are partially ideological and cultural, in terms whose science should count and be taught in school science, in addition to practical matters of resources and opportunities. Now that science content standards are established, efforts should be focused on how to implement standards-based assessments and how to ensure access and achievement for all students. The alignment of assessment with the content standards, as well as the attainment of the standards by all students, are key challenges to standards-based and systemic reform in large education systems.

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